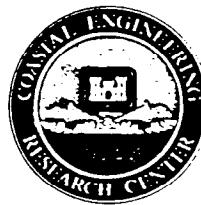




# Coastal Engineering Technical Note



## LOW-ALTITUDE PHOTOGRAHMETRIC MONITORING OF COASTAL STRUCTURES

### PURPOSE:

To provide information relative to monitoring coastal structures using limited ground surveys, properly acquired low-altitude aerial photographs, and photogrammetric analysis.

### INTRODUCTION:

Under the Monitoring Completed Coastal Projects (MCCP) program, a technique has recently been developed and used to obtain precise vertical and horizontal positions of all visible armor units on coastal structures. The procedure utilizes limited ground-based surveys, low-level aerial photography, and photogrammetric analysis. After initial, or base level conditions are established, subsequent surveys may be used to precisely quantify armor unit movement.

Low altitude photogrammetric monitoring of the 548-m-long (1,800-ft-long) St. Paul Harbor, Alaska, Outer Breakwater was completed in May 1994, monitoring of a cumulative 1,506-m (4,940-ft) length of the Cleveland Harbor, Ohio, East Breakwater was completed in October 1993, and the seaward most 183 m (600 ft) of the north jetty at Yaquina Bay, Oregon, was monitored in 1992 and 1993. The St. Paul Harbor breakwater consists of 16,300-kg (18-ton) armor stone. The majority of the Cleveland structure monitored, included 1,800-kg (2-ton) dolos armor units, but two stone sections (3,900 to 8,700- and 8,200 to 18,100-kg (4.3 to 9.6- and 9 to 20-ton) armor units) also were monitored. The portion of the Yaquina North Jetty monitored included armor stone weighing up to 29,500 kg (32.5 ton). The St. Paul Harbor and Yaquina Bay work were conducted under the St. Paul Harbor, Alaska, and Yaquina Bay, Oregon, work units, respectively, and the Cleveland Harbor work was conducted as part of the Periodic Inspections work unit of the MCCP program.

### DESCRIPTION OF PROCEDURES:

#### Targeting and Ground Surveys

The ground survey provides reference control points needed to set up stereoscopic photogrammetric models from which measurements are made. Monuments are initially established on land and on the cap of the breakwaters to serve as control (both

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horizontal and vertical reference) for ground based survey work as well as photogrammetric work. Ground surveys are initiated on known monuments. Using global positioning system (GPS) control surveying and electronic land surveying techniques, monuments are established on the coastal structures at approximate 152 m (500 ft) intervals along the study areas. The monuments were established by permanently cementing 7.6-cm (3-in) brass disks in the structure.

In addition to the monuments, targets are established at intervals of approximately 18.3 m (60 ft) along the seaside, landside, and approximate center of the breakwaters for the length of each study area. Each station was marked with a drill hole 0.6-cm (1/4-in) in diameter, and 0.6-cm (1/4-in) deep, and painted with a circular target to ensure visibility in the aerial photography. Ground surveys of the targets are used to form control by which the accuracy of the photogrammetric survey work can be validated and defined.

#### Low-Altitude Aerial Photography

Aerial photography is a very effective means of capturing images of large areas for later analysis, study, and visual comparison to previous or subsequent photography, or measurement and mapping. Its chief attribute is the ability to freeze a moment in time, while capturing extensive detail. To maximize coastal structure armor unit exposure and minimize shadows; photography should be obtained when low water and high sun angle (between 1100 and 1300 hours) occur simultaneously. High visibility and calm weather also are important factors for a successful aerial photographic flight.

Aerial photography along the areas of the breakwaters being monitored may be obtained with an aerial mapping camera (22.9-cm by 22.9-cm (9-in by 9-in) format). The photos are secured from a helicopter flying at low altitude (36.6 to 54.9 m, 120 to 180 ft), which results in high resolution images and contact prints with scales of 2.5-cm (1-in) on the aerial photography equal to 6.1 to 12.2 m (20 to 40 ft) in the prototype. Photographic stereo pairs, with at least 60 percent overlap are secured during the flights.

#### Photogrammetric Analysis of Armor Units

When aerial photography is planned and conducted so that each photo overlaps the next by 60 percent or more, the two photographs comprising the overlap area can be positioned under an instrument called a stereoscope, and viewed in extremely sharp three-dimensioned detail. If properly selected survey points on the ground have previously been targeted and are visible in the overlapping photography, very accurate measurements can be

obtained of any point appearing in the photographs. The technique is called photogrammetry.

Low-altitude stereo pair images obtained during aerial photography of the coastal structures were viewed in a stereoscope, and stereomodels were oriented to the monument and target data established during the ground surveys. In the stereomodel, extremely accurate horizontal and vertical measurements can be made of any point on any armor unit appearing in the print. Maximum differences between the ground and stereomodel elevations are usually less than 0.9 cm (0.03 ft) with typical differences much less. Thus, the stereomodels are very accurate as evidenced by verification with the ground control surveys. Stereomodels were used for all photogrammetric compilation and development of orthophotography.

PRODUCTS:

Orthophotos combine the image characteristics of a photograph with the geometric qualities of a map. The digital orthophoto is created by scanning aerial stereo pairs with a precision image scanner. The scanned data file is digitally rectified to an orthographic projection by processing each image pixel. Orthophotos are prepared for the portions of the breakwaters monitored. An example of an orthophoto is shown in Figure 1. Precise horizontal measurements may be obtained from the orthophoto using an engineer scale since the image has been rectified and is free from skewness and geometric distortion.

In addition to digital orthophotos, point plot maps, contour maps, and cross-sections may be developed for the monitored portions of the breakwaters using the digital terrain model (DTM). Point plot maps consisted of a 0.3-m (1-ft) grid pattern overlaid on the structures. Precise vertical and horizontal measurements are obtained at the intersections of the grid. Contour maps of the areas of the breakwaters monitored were generated from the DTM grid on 0.3-m (1-ft) intervals. In addition, using the analytical stereoplotter and the DTM grid, cross sections of the breakwater were developed at various intervals along the structures. All digital data, photogrammetric compilations and analysis, image points, and map data are stored on diskettes in Intergraph files. The data may be retrieved and compared against data obtained during subsequent monitoring.

Photogrammetric monitoring of coastal structures was first conducted by the Corps of Engineers on the dolos-rehabilitated jetties at Manasquan Inlet, NJ, in the mid 1980's. For this study, aerial photos were obtained from a fixed-wing aircraft at higher altitudes, and photogrammetric maps were established by tracing the armor units' shapes on transparent drafting material.



Figure 1. Example of an orthophoto for a portion of Cleveland Harbor East Breakwater, Ohio

SUMMARY:

By means of limited ground-based surveys, low-level aerial photography, and photogrammetric analysis, very precise positions of armor units have been established for portions of the Cleveland Harbor, OH, East Breakwater, the Yaquina Bay, OR, North Jetty, and the outer St. Paul Harbor, AK, Breakwater. Accuracy of the photogrammetric analysis technique were validated and defined through comparison of ground and aerial survey data on monuments and targeted armor units. A method using high resolution, stereo pair photographs, a stereoplotter, and Intergraph based software has been developed to analyze the entire above water armor unit fields. Now that a permanent record has been developed at a point in time, subsequent armor unit movement data may be quantified very precisely during future surveys. Assessments can be made on the long term response of the structures to their environment. Insight gathered from these efforts will allow engineering decisions to be made as to whether or not closer surveillance and/or repair of the structures are required to reduce their chances of failing catastrophically. In addition, methods developed and validated for the Cleveland, Yaquina, and St. Paul Harbor structures may be used to gain insight into other Corps' structures.

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